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(54) Abstract Title
White light emitting LED devices

(57) A light emitting device provides a light emitting diode 6 comprising a light emitting layer, which produces non-white light, and a sapphire substrate interposed between the light emitting layer and a light conversion layer 5 to convert light emitted by the LED into apparently white-light. The light emitting layer may comprise GaN, InGaAs or GaAlN emitting blue or UV light, and the conversion layer may contain a scattering medium and a fluorescent material containing one or more phosphors. A reflector such as a diffuser, scatter plate, lens or mirror may be placed above or below the LED, and an optical mechanical device such as a lens array or binary optics device may be included between the conversion layer and the reflector.

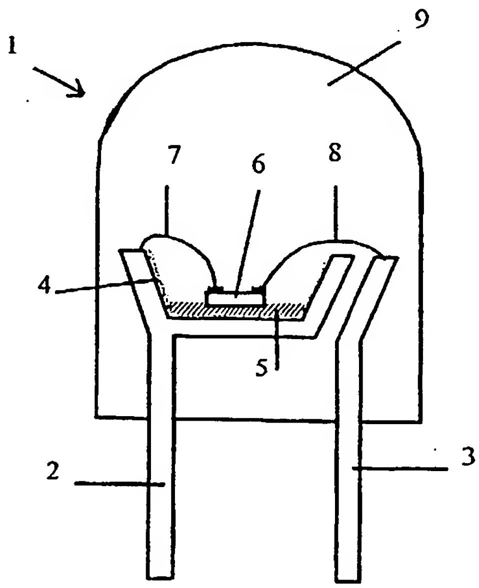

Fig.1

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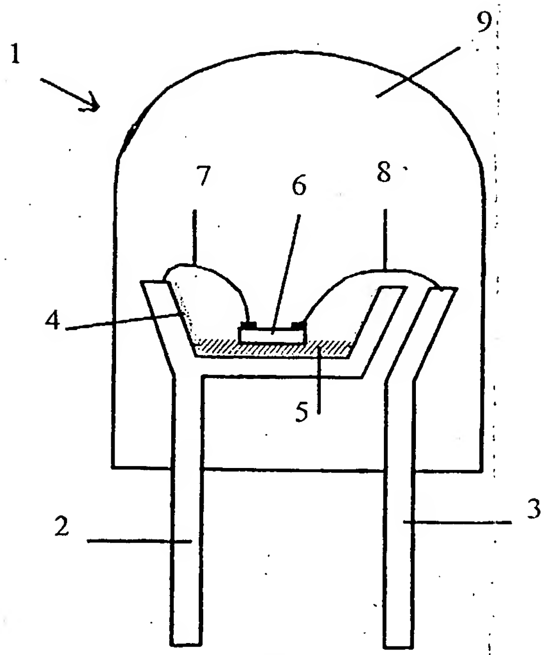

Fig.1

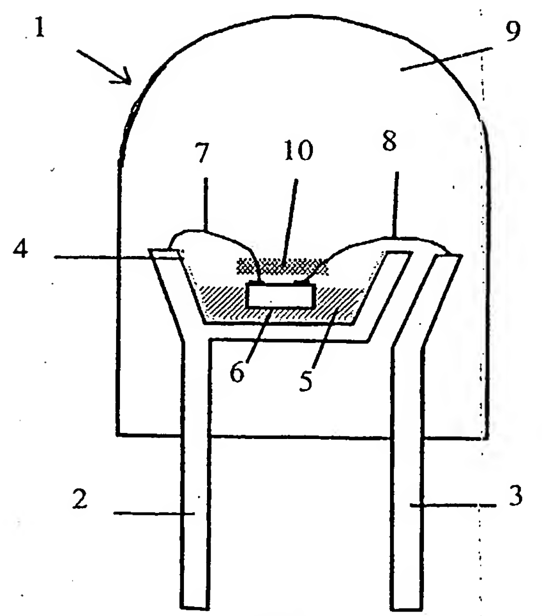

Fig.2

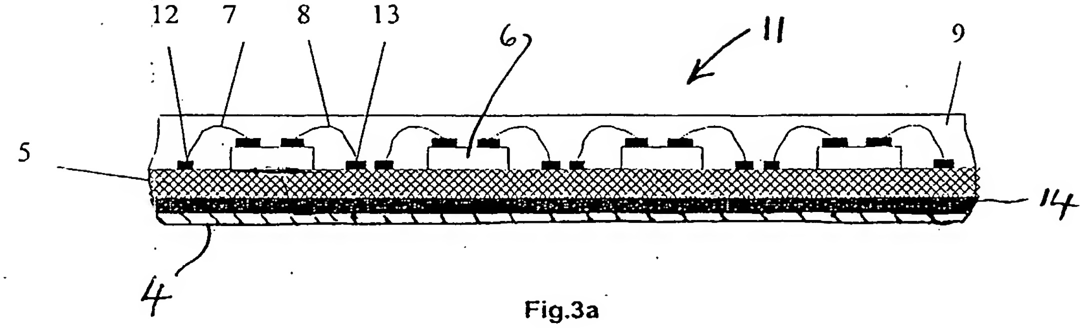

Fig.3a

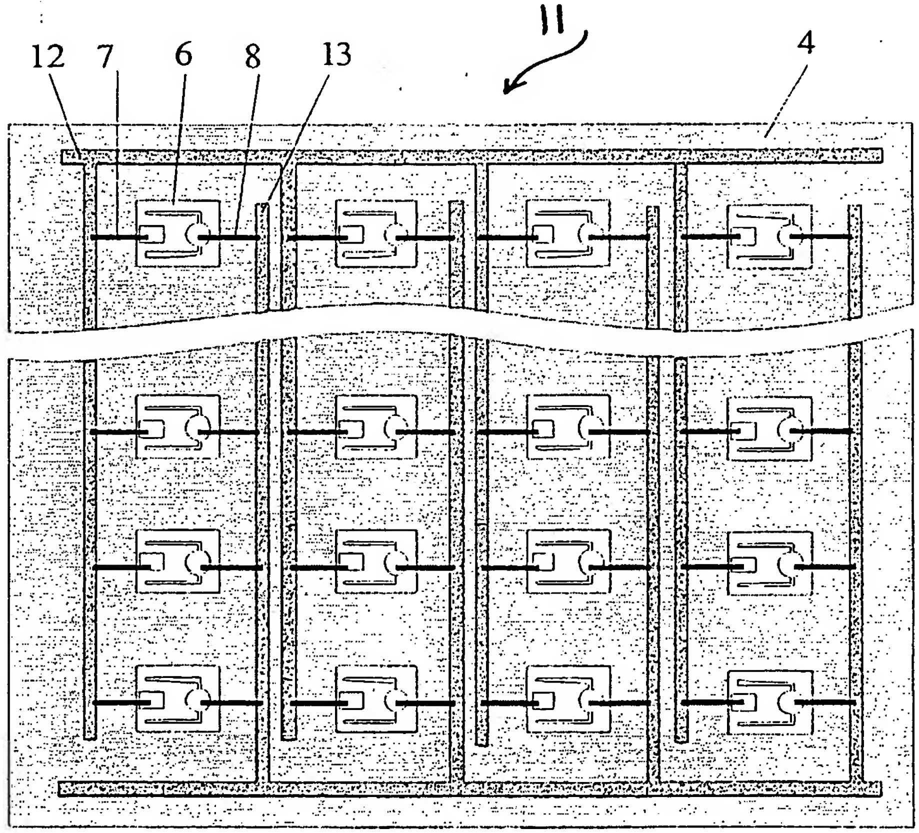

Fig.3b

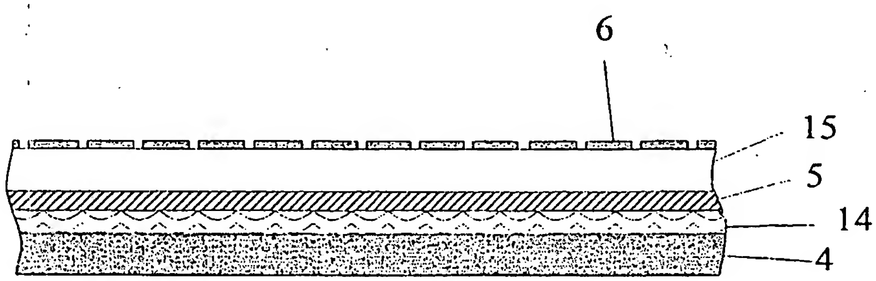

Fig.4a

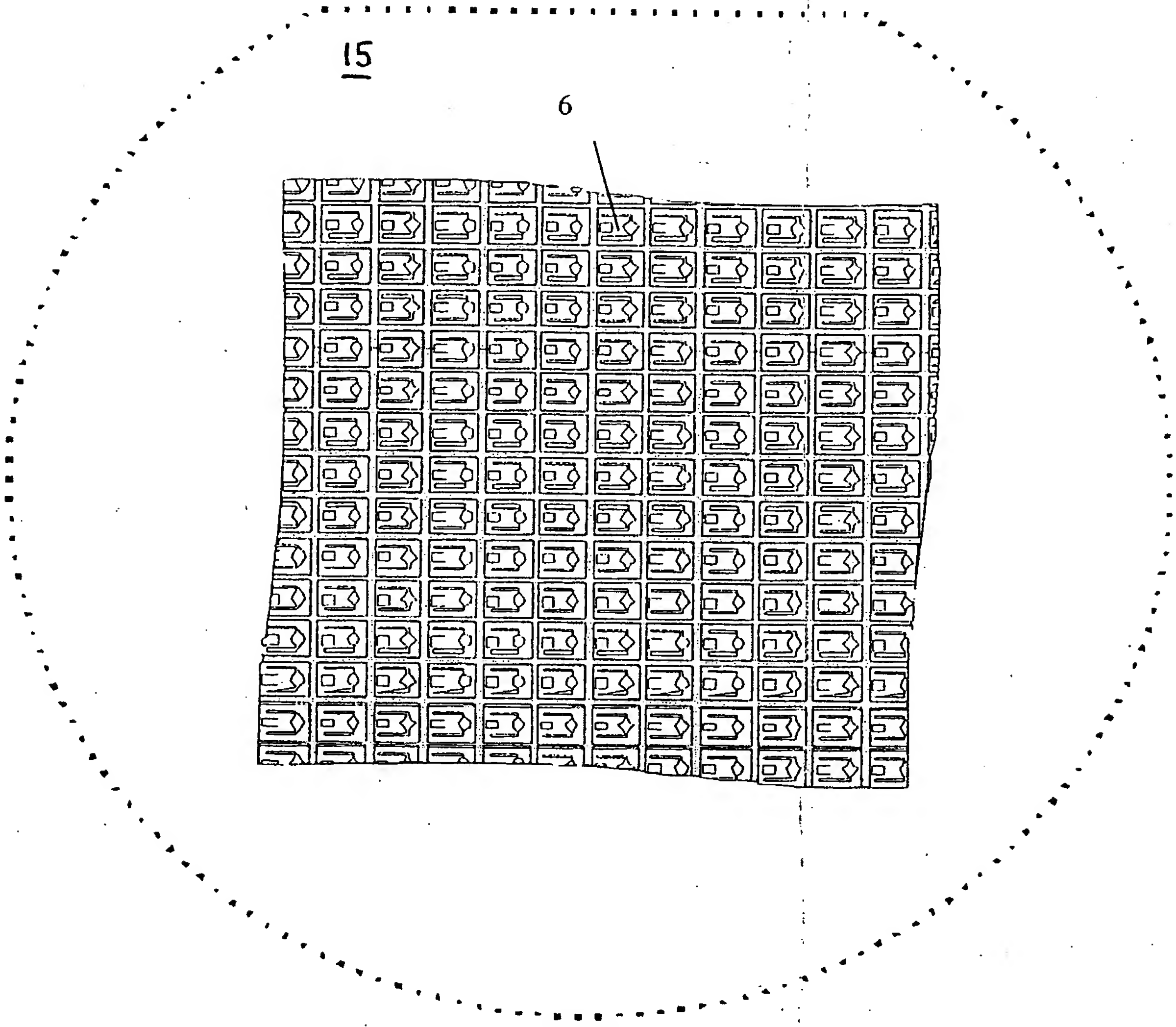

Fig.4b

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LIGHT EMITTING DEVICES

The present invention relates to light emitting devices.

More particularly, the present invention relates to devices that use a non-white light emitting diode (LED) in combination with a light conversion layer to create a light emitting device that gives off white-appearing light. White light generally ranges from 400 to 600 nanometres (nm) in wavelength, but light which appears as a proper combination of red, blue and green will also appear as white.

By using one or more of GaN, InGaN and GaAlN in a LED, it is possible to create a LED that produces an intense blue light at around 470nm or ultra-violet light at around 400 nm. White light can be generated, for example, by a device that uses such a LED if it is then combined with a light conversion layer which absorbs blue light, converts it and subsequently emits it as light in the yellow-orange range of the spectrum. The yellow-orange light mixes with the remaining blue light from the LED to provide a combination of light which appears as white to the human eye.

A conventional approach in building such a light emitting device is to use a conversion layer containing a fluorescent material and layer the conversion layer on to the top of a blue light emitting LED. However, this produces inefficient light conversion, as the blue light may escape past or be inhibited by the phosphor grains in the conversion layer. Furthermore, if an epoxy resin encapsulation is provided, this may also absorb some of the blue light. Thus, a high rate of conversion and high brightness are not easily achieved using this approach. This is the case whether the device in question is a LED lamp or a surface mounted LED light and the approach does not take into account the possibility of using a transparent substrate for the LED.

According to the present invention, there is provided a light emitting device comprising:

i) a light emitting diode (LED) comprising a light emitting layer on a substrate, the LED emitting, in use, a non-white light; and

ii) a light conversion layer beneath the LED, the substrate being interposed between the light conversion layer and said light emitting layer and the conversion layer being capable of converting non-white light of the wavelength or wavelengths emitted by the LED to light of a different wavelength or wavelengths, the arrangement being such that, in use, a plurality of wavelengths of light are produced resulting in substantially white-appearing light.

Said light emitting layer could be an epitaxial layer.

The LED substrate is preferably transparent so as to provide a pathway for at least some of the light emitted by the LED to contact the light conversion layer.

The light emitting device may further comprise a reflector device positioned above the LED (with or without a gap, such as an air gap) so as to provide a pathway for at least some of the light emitted by the LED to contact the light conversion layer. The reflector device may comprise one or more of a diffuser, scattering plate, a lens, and a mirror .

The conversion layer may comprise fluorescent material dispersed in a transparent medium. The fluorescent material may comprise one or more phosphors. The conversion layer may further comprise a scattering medium to enhance the uniformity of the converted light.

The light emitting device may further comprise a reflective layer positioned beneath the conversion layer and operative to reflect light of the wavelengths produced by the LED and conversion layer. The reflective layer may employ dielectric mirrors or metallic reflectors.

The light emitting device may further comprise an optical mechanical device interposed between the conversion layer and the reflective layer to improve the uniformity, brightness and beam convergence of the converted light. The optical mechanical device may comprise a microlens array, a lenticular lens array or a binary optics device.

The non-white light produced by the LED may be blue or UV light. The LED light emitting layer may comprise one or more of GaN, InGaN and GaAlN.

The LED substrate may comprise sapphire.

Where the LED produces blue light, the light conversion layer may comprise phosphors capable of converting blue light to light in the yellow-orange range, such that the combination of light produced by the LED and conversion layer appears substantially white. Such phosphors may comprise one or more of $Y_3Al_5O_2$:Ce, (Y, Gd)$_3Al_5O_2$:Ce, ZnS:Cu, ZnS:Mn, SrCaS:Bi and SrS:Eu.

Where the LED produces UV light, the light conversion layer may comprise a combination of different types of phosphor, each type being capable of converting UV light into a colour of light in the visible spectrum, the combination of light thereby produced by the conversion layer may appearing substantially white. For example, the light conversion layer may comprise one or more of a UV to blue light converting phosphor, a UV to green light converting phosphor and a UV to red light converting phosphor. Such a UV to blue light converting phosphor may comprise $BaMgAl_{10}O_{17}$:Eu or ZnS:Ag or a combination thereof, such a UV to green light converting phosphor may comprise ZnS:Cu and such a UV to red converting phosphor may comprise Y_2O_2S or SrS:Eu or ZnS:Mn or a combination thereof.

The light emitting device may comprise a plurality of such LEDs arranged in a linear, 2-dimensional matrix or array, or a 3-dimensional matrix or array. Alternatively, the light emitting device may comprise a plurality of such LEDs formed on a wafer. The light emitting device may further comprise p- and n-type ohmic contacts located at the top of the wafer.

According to the present invention from another aspect, there is provided a light emitting device comprising:

a UV or blue light emitting LED made from an epitaxial layer comprising one or more of GaN, InGaN and GaAlN on a transparent sapphire substrate;

a conversion layer beneath the LED containing organic or inorganic fluorescent material;

a UV/visible light reflecting layer beneath and around the fluorescent material and the LED;

an optical mechanical device, such as a microlens array, formed between the conversion layer and the reflecting layer; and

input terminals connected to the LED, the assembly being free-standing or embedded in a transparent encapsulation resin.

According to the present invention from a further aspect, there is provided an LED comprising:

a wafer having UV or blue light emitting LEDs made from an epitaxial layer comprising one or more of GaN, InGaN and GaA1N on a transparent sapphire substrate;

a conversion layer beneath the LED containing organic or inorganic fluorescent material;

a UV/visible light reflecting layer beneath the fluorescent material and the LED;

an optical mechanical device, such as a microlens array, between the conversion layer and the reflecting layer; and

p- and n-type ohmic contacts locating at the top of the wafer.

In one example, a UV or blue light emitting LED is made from an epitaxial layer of one or more of GaN, InGaN and GaAlN on a transparent sapphire substrate. The UV or blue light can pass through the transparent substrate and strike phosphor grains and first conversion light from the phosphors occurs. Unabsorbed UV or blue light that escapes past the phosphors is reflected by a reflector and strikes the phosphors again to induce second conversion light from the phosphors.

In another example, a LED chip is covered (with or without a gap such as an air gap) by one or more of a diffuser, a scattering plate, a lens and a mirror, which partially reflects or scatters back UV or blue light emitted from LED chip. Approximately up to 100% of UV light emitted from the front side of the LED chip can be reflected back. Approximately up to 50% of blue light emitted from the front side of the LED chip can

be reflected or scattered back and strike phosphors of the conversion layer. The tuning of the reflectivity can be done by a dielectric coating or the choice of plates with different refractive indices. It can provide a higher conversion efficiency and more uniformly white light.

Embodiments of the invention will now be described, by way of example, with reference to the following drawings, in which;

FIG. 1 is a cross-section of a LED lamp;

FIG. 2 is a cross-section of the LED lamp of FIG. 1, further comprising a partial reflector;

FIG. 3a is a cross-section of a light emitting device including a LED array;

FIG. 3b is a plan-view of the device of FIG. 3a;

FIG. 4a is a cross-section of a light emitting device including a LED wafer; and

FIG. 4b is a plan-view of the device of FIG. 4a.

Referring now to FIG. 1, a LED lamp 1 comprises a LED 6, capable of producing blue or UV light, and first and second terminals, or lead frames, 2 and 3, the LED 6 being seated in a recessed area of lead frame 2. Optionally, the entire assembly can be embedded in a transparent encapsulation resin 9. The LED 6 comprises a light emitting epitaxial layer of one or more of GaN, InGaN and GaAlN on a transparent sapphire substrate. The recessed area of lead frame 2 is covered by a reflective layer 4. Alternatively, the reflective layer 4 may be integral with the recessed area of lead frame 2. The reflective layer 4 can be formed of multilayer dielectric mirrors, metallic reflectors such as Al or Ag, or other materials that reflect UV and visible light.

Interposed between the LED 6 and the reflective layer 4 is a light conversion layer 5. The light conversion layer 5 can be formed by dispersing a fluorescent material in a transparent polymer material, such as polystyrene, polyacrylate, epoxy resin or other transparent medium. The fluorescent material can be one or more of $Y_3Al_5O_2$:Ce, $(Y, Gd)_3Al_5O_2$:Ce, ZnS:Cu, ZnS:Mn and SrCaS:Eu, or any other phosphor which can convert blue or UV light to the yellow-orange range. The light conversion layer 5 may

also contain a scattering media such as dielectric materials, glass or air bubbles to enhance the uniformity of the converted light.

Electrical power is supplied by first and second lead frames 2 and 3 to the LED 6 via wire bonds 7 and 8 respectively. When activated by a DC current at the appropriate forward voltage, the light emitting layer of the LED 6 produces a blue light at approximately 470 nm and UV light at approximately 400nm wavelengths. Light emitted from the rear face of the light emitting layer (the face in contact with the transparent sapphire substrate) passes through the transparent sapphire substrate and strikes the phosphor grains in the light conversion layer 5 beneath it. On striking the phosphor grains, a first conversion of light occurs. Blue or UV light that escapes past the phosphor grains is reflected by reflective layer 4 and strikes the phosphor grains again, inducing a second conversion of light to occur. The converted light combines with the remainder of the blue light emitted by the LED 6 to produce a combination of light that appears substantially white to the human eye.

Referring now to FIG. 2, the LED lamp 1 may also comprise a reflector device 10, positioned over the top of the LED 6 with or without a gap. On activation of the LED 6, at least some of the light emitted from the front face of the light emitting layer (the face not in contact with the transparent sapphire substrate) encounters the reflector device 10. Some of the light encountering the reflector device 10 is then reflected back towards the light conversion layer 5, whereupon conversion of light occurs, as before. The reflector device 10 may comprise one or more of a diffuser, a scattering plate, a lens or a mirror. The properties of a diffuser are dictated by its surface texture, and in particular the reflectivity on the bottom of the diffuser can be tuned by the choice of plates of appropriate refractive index or the deposition of multilayer dielectric thin films. A scattering plate can be made of a transparent polymer dispersed with scattering media such as dielectric beads, glass beads or air bubbles to scatter the light emitted by the LED 6. A lens can be of any desired design depending on the output beam requirements. Approximately up to 50% of blue light and 100% of UV light emitted from the front face of the light emitting layer can be reflected back.

Large, two-dimensional, light-emitting devices can be readily manufactured in that a LED array is combined with the conversion and reflecting layers. For example, such a LED array may be surface mounted on a reflecting layer which is printed or covered by fluorescent material.

Referring now to FIG. 3a, there is shown a white LED array 11 with a reflecting module, which consists of a layer 5 of fluorescent material underneath the LED 6. The fluorescent material can be dispersed in a transparent polymer material, such as polystyrene, polyacrylate, epoxy resin or other transparent medium. An optical mechanical device 14 such as a microlens arrays, lenticular lens arrays, or a binary optics device is fabricated between the conversion layer 5 and the reflecting layer 4. The LED array 11 has first and second terminals, or metal contacts, 12 and 13, by which electrical power is supplied to the LED array 11. Each LED 6 is connected by a wire bond 7 to a metal contact 12 and by a wire bond 8 to a metal contact 13. The entire assembly can be free standing or embedded in a transparent encapsulation resin 9.

FIG. 3b is a plan-view of the white LED array 11 of Fig. 3a. Each LED 6 is surface mounted on the layer 5 containing fluorescent material and reflecting layer 4. LED array 11 has first and second terminals, or metal contacts, 12 and 13, by which electrical power is supplied to the LED array 11. Each LED 6 is connected by a wire bond 7 to a metal contact 12 and by a wire bond 8 to a metal contact 13.

Referring now to FIGS. 4a and 4b, there is shown a white LED wafer 15 with its reflecting and conversion layers attached on the bottom. The conversion layer 5 may comprise a fluorescent material dispersed in a transparent polymer. The conversion layer may also contain scattering media to enhance the uniformity of the converted light. An optical mechanical device 14 between the conversion layer 5 and the reflecting layer 4 may be fabricated to form lenticular lens array, a two dimensional microlens array, or a binary optics device to improve the uniformity, brightness and beam convergence of the converted light. The reflecting layer 4 can be metal reflectors or dielectric mirrors. The fluorescent material can be dispersed in a transparent polymer material, such as polystyrene, polyacrylate, epoxy resin or other transparent medium. Each LED 6 has the necessary features for a functional substantially white light emitting device.

CLAIMS

1. A light emitting device comprising;
i) a light emitting diode (LED) comprising a light emitting layer on a substrate, the LED emitting, in use, a non-white light; and
ii) a light conversion layer beneath the LED, the substrate being interposed between the light conversion layer and the light emitting layer and the conversion layer being capable of converting non-white light of the wavelength or wavelengths emitted by the LED to light of a different wavelength or wavelengths, the arrangement being such that, in use, a plurality of wavelengths of light are produced resulting in substantially white-appearing light.

2. A light emitting device according to Claim 1, wherein the light emitting layer is an epitaxial layer.

3. A light emitting device according to Claim 1 or 2, wherein the LED substrate is transparent so as to provide a pathway for at least some of the light emitted by the LED to contact the light conversion layer.

4. A light emitting device according to any preceding claim, wherein the light emitting device further comprises a reflector device positioned above the LED so as to provide a pathway for at least some of the light emitted by the LED to contact the light conversion layer.

5. A light emitting device according to Claim 4, wherein the reflector device comprises one or more of a diffuser, a scattering plate, a lens or a mirror.

6. A light emitting device according to any preceding claim, wherein the conversion layer comprises fluorescent material dispersed in a transparent medium.

7. A light emitting device according to Claim 6, wherein the fluorescent material comprises one or more phosphors.

8. A light emitting device according to Claim 6 or 7, wherein the conversion layer further comprises a scattering medium.

9. A light emitting device according to any preceding claim, wherein the light emitting device further comprises a reflective layer positioned beneath the conversion layer operative to reflect light of the wavelengths produced by the LED and conversion layer.

10. A light emitting device according to Claim 9, wherein the reflective layer employs dielectric mirrors or metallic reflectors.

11. A light emitting device according to any preceding claim, wherein the light emitting device further comprises an optical mechanical device interposed between the conversion layer and the reflective layer.

12. A light emitting device according to Claim 11, wherein the optical mechanical device comprises a microlens array, a lenticular lens array or a binary optics device.

13. A light emitting device according to any preceding claim, wherein the non-white light produced by the LED is blue or UV light.

14. A light emitting device according to Claim 13, wherein the LED light emitting layer comprises one or more of GaN, InGaN and GaAlN.

15. A light emitting device according to any preceding claim, wherein the LED substrate comprises sapphire.

16. A light emitting device according to Claim 13 or either of Claims 14 and 15 as dependent on Claim 13, wherein the LED produces blue light and the light conversion layer comprises phosphors capable of converting blue light to light in the yellow-orange range, such that the combination of light produced by the LED and conversion layer appears substantially white.

17. A light emitting device according to Claim 16, wherein the phosphors comprise one or more of $Y_3Al_5O_2$:Ce, (Y, Gd)$_3Al_5O_2$:Ce, ZnS:Cu, ZnS:Mn, SrCaS:Bi and SrS:Eu.

18. A light emitting device according to Claim 13 or either of Claims 14 and 15 as dependent on Claim 13, wherein the LED produces UV light and the light conversion layer comprises a combination of different types of phosphor, each type being capable of converting UV light into a colour of light in the visible spectrum, the combination of light thereby produced by the conversion layer appearing substantially white.

19. A light emitting device according to Claim 18, wherein the light conversion layer comprises one or more of UV to blue light converting phosphor, a UV to green light converting phosphor and a UV to red light converting phosphor.

20. A light emitting device according to Claim 19, wherein such a UV to blue light converting phosphor comprises $BaMgAl_{10}O_{17}$:Eu or ZnS:Ag or a combination thereof, such a UV to green light converting phosphor comprises ZnS:Cu and such a UV to red converting phosphor comprises Y_2O_2S or SrS:Eu or ZnS:Mn or a combination thereof.

21. A light emitting device according to any preceding claim, comprising a plurality of such LEDs arranged in a linear, 2-dimensional matrix or array, or a 3-dimensional matrix or array.

22. A light emitting device according to any one of Claims 1 to 20, wherein the light emitting device comprises a plurality of such LEDs formed on a wafer.

23. A light emitting device according to Claim 22, wherein the light emitting device further comprises p- and n–type ohmic contacts located at the top of the wafer.

24. A light emitting device, substantially as herein described with reference to the accompanying drawings.

The Patent Office

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Application No: GB 0106038.3
Claims searched: 1-24

Examiner: Harvey Dobbs
Date of search: 12 February 2002

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): H1K (KQAAC, KQAAF)

Int Cl (Ed.7): H01L 33/00; H05B 33/00

Other: Online: EPODOC, WPI, PAJ

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X,E	EP 1107321 A1	(CITIZEN) Fig. 3,17,19-21; col. 6, line 35 - col 8, line 17; col. 11, lines 17 - 38	1-3, 6-10, 13-17,21-23
A	WO 01/24285 A1	(LUMILEDS)	
X	US 5966393	(REGENTS) Fig. 6; col 8, lines 19-22	1-3, 6-10, 13-17
X	US 5898185	(IBM) Fig. 7; col 4, lines 40-51	1-3, 6-8, 13-15,18-20,23
A	JP 2000-347601	(TOSHIBA)	

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